1.1a Mg, Ca, PO4 and Fe in metabolism

Bio Factsheet

Number 60

Minerals in Plants and Animals

Plants gain their minerals by direct absorption from the soil whereas animals gain their minerals via their diet. Although a wide range of mineral types are essential in both plants and animals, most examination boards only expect candidates to have a detailed knowledge and understanding of the uptake, transport and roles of nitrates, phosphates, magnesium and calcium in plants, and of the sources and roles of phosphates, chloride, calcium, iron, sodium and potassium in humans. Thus questions must be expected on these topics.

> ***Remember -*** *examiners may still set data interpretation and application questions on other minerals not specified in the syllabuses.*

Macronutrients and micronutrients

Macronutrients are minerals which are required in relatively large quantities. In plants they are nitrates, phosphates, potassium, calcium, magnesium, sulphur and iron. In animals they are phosphate, chloride, sodium, potassium, calcium, and iron.

Micronutrients are minerals (trace elements) that are required only in minute quantities. Intake of large quantities of them may be toxic and might cause illness and death. In plants they include zinc, copper, boron and molybdenum. In animals they include zinc, iodine, fluorine, copper, cobalt and manganese.

The roles of minerals in plants

Table 1. shows the roles of some of the more important minerals in plants.

Uptake of minerals by plants

Minerals in the soil, existing within the soil particles, dissolve and ionise into the soil water thus making the soil solution. Minerals are similarly released from the microbial decay of soil dead organic matter (such as leaf litter and dead organisms) and from humus. Humus is the organic matter that has partially decayed so that it is amorphous (has no recognisable form).

Plants absorb the minerals from the soil solution, mainly via the root hairs. A small amount of absorption probably occurs over other areas of the root surface, such as via the piliferous layer cells between the root hairs.

The ions in the soil solution enter the plant by both passive and active transport. **Passive transport** involves the **apoplastic pathway**. This is the system of continuous cellulosic cell walls from the surface piliferous layer to the endodermis. These walls contain water and dissolved ions which can flow from the soil to the endodermis, via the cellulosic walls, under the pull of the transpiration stream.

Table 1. Roles of minerals in plants

Mineral	Roles
Nitrate*	Reduced to nitrite by **nitrogen reductase** during **amino acid synthesis**. Used in the synthesis of proteins, nucleic acids, chlorophyll and many coenzymes.
Phosphate*	Component of DNA and RNA and of energy carrying coenzymes, such as ATP. Component of phospholipids found in cell membranes.
Sulphate	Component of sulphur containing amino acids (eg. cysteine) and some proteins. Component of coenzyme A. Deficiency causes '**chlorosis**' (yellowing of leaves due to a failure in chlorophyll synthesis).
Magnesium*	Component of chlorophyll molecules. Deficiency causes '**chlorosis**' due to a failure to synthesise chlorophylls. Magnesium pectate is a component of the middle lamella of cell walls.
Calcium*	Calcium pectate is the main component of the middle lamella of cell walls. Deficiency results in stunted growth due to poor cell wall development.
Iron	Needed as a cofactor in chlorophyll synthesis. It is a cofactor for peroxidase enzymes, such as catalase. Deficiency results in '**chlorosis**' due to poor chlorophyll synthesis.
Zinc	As a cofactor for alcohol dehydrogenase required for anaerobic respiration. Deficiency causes leaf malformations in some plants.
Potassium	Required as a cofactor for some photosynthetic enzymes. Deficiency causes yellow and brown leaf margins and premature leaf death.
Molybdenum	Needed as a cofactor for the enzyme **nitrate reductase** which catalyses the reduction of nitrate to nitrite during amino acid synthesis. Deficiency causes a reduction in growth rate.
Boron	Needed as a cofactor during mitosis in meristems. Deficiency results in abnormal growth and death of shoot tips, 'stem-crack' in celery and 'heart-rot' of beet.

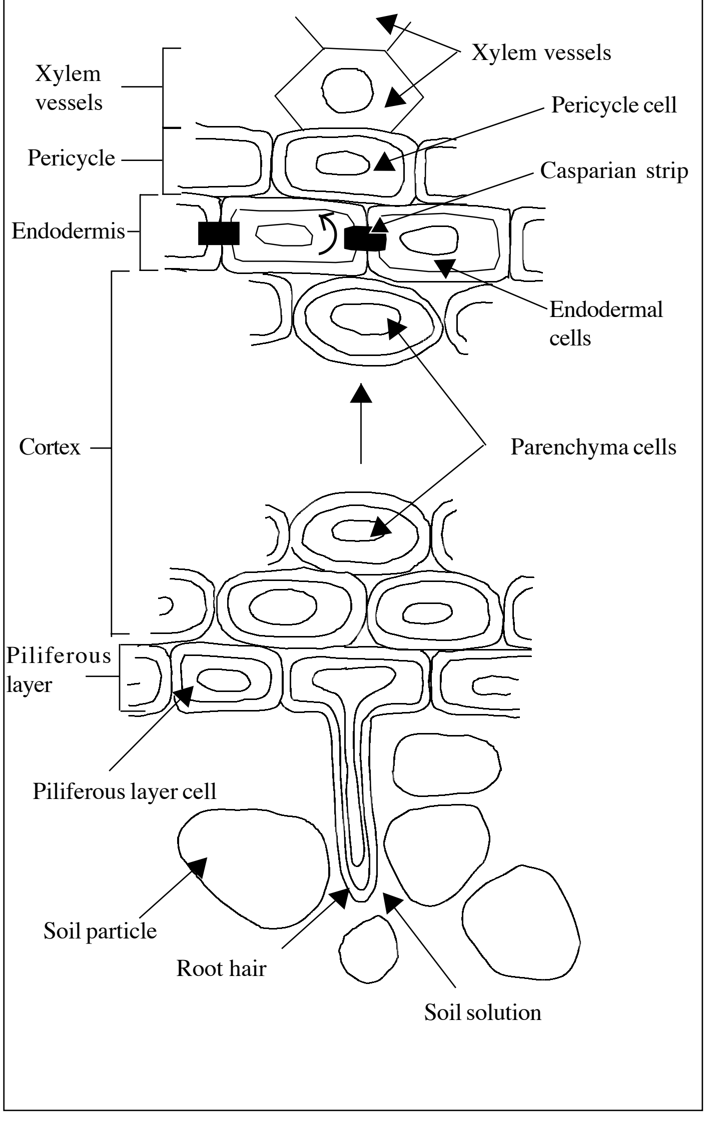
* specifically named on most syllabuses.

The water and ions of the soil solution enter the cell walls of the root hairs and piliferous layer cells by mass flow and by diffusion. The water and ions are eventually drawn up the xylem vessels to the leaves, stem and flowers. This maintains the gradients causing uptake of water and salts from the soil. This method of mineral uptake does not require an energy input from respiration and does not discriminate in the type of ions it absorbs.

Active transport occurs from the soil solution into the root hair cells. It also occurs into the cortex parenchyma cells from the solution in the apoplast pathway. These uptakes require the expenditure of respiratory energy in the form of ATP and are selective.

The plasma membranes and tonoplasts are differentially permeable and so only allow certain molecules in specific quantities through into the cytoplasm and vacuole. The cell membranes contain specific carrier molecules which give them their selectivity. Active transport also enables the minerals to be accumulated against the concentration gradient. The ions can then be passed from cell to cell, without having to cross further cell membranes, by simple diffusion across the **sympastic pathway**. This is the system of protoplasts across the cortex which interconnect by strands of cytoplasm, joining from cell to cell through pores in the cell wall. These strands of cytoplasm are called **plasmodesmata**. Fig 1. shows the structure of the root hair and cortex.

Fig 1. Transverse section through the root cortex in the piliferous (root hair) zone



Casparian Srips

Note in Fig 1. that the radial walls of the endodermal cells are thickened with water-impermeable suberin called **Casparian strips**. These effectively block the apoplastic passage of water and salts through the cellulose walls to the pericycle cells (parenchymatous starch storing cells) and thus xylem vessels.

> ***Remember –*** *the salts coming through this apoplast pathway are the same as in the soil solution and have not undergone selective absorption.*

The endodermal cells can still pass water (by osmosis) and salts (by active transport) through to the pericycle and xylem via the symplast pathway (through cytoplasmic plasmodesmata). Thus water and salts can pass from the apoplastic path into the cytoplasm and vacuoles of the endodermal cells, as it does into the parenchyma cells across the cortex. The endodermis, by virtue of its Casparian strips, thus imposes selectivity on the salts that pass through to the pericycle and xylem. Once in the xylem vessels the salts are carried upwards in the transpiration stream.

The roles of minerals in humans

Absorption of salts from the diet

Absorption of minerals into the blood mainly occurs in the ileum (part of small intestine). Sodium ions are able to move through the epithelial cells by diffusion. They are also actively transported into the epithelial cells from where they can diffuse to the blood.

> ***Remember –*** *the carrier protein for sodium ions also has sites for carrying glucose and galactose. Unless all three sites are occupied the carrier will not work. A question about this has been used by one exam board.*

Chloride, iodide and nitrate ions passively follow sodium ions or may be absorbed by active transport. Calcium ions are actively transported under the control of vitamin D, calcitonin and parathyroid hormone. Other minerals, such as iron, potassium, magnesium and phosphate are also absorbed by active transport.

The regulation of calcium

The absorption of calcium ions (and phosphate) from the gastrointestinal tract requires the presence of **vitamin D** in its activated form. If active vitamin D is deficient then calcium cannot be absorbed and abnormalities may appear in the bones. In children this may cause **rickets** with the symptoms of stunted growth and bent limb bones. In adults it can cause **osteomalacia** where the bones become weak and fragile due to loss of calcium and phosphate.

> ***Remember –*** *vitamin D precursors are changed to inactive vitamin D in the skin when irradiated with sunlight. The vitamin D undergoes modification in the liver and then kidney before it becomes active.*

The thyroid hormone calcitonin lowers the levels of calcium and phosphate in blood by inhibiting breakdown of bone and promoting the uptake of calcium and phosphate into bone.

The hormone parathormone from the parathyroid glands has the following effects:

- it stimulates the activation of vitamin D.
- it promotes the absorption of calcium and phosphate from the gastrointestinal tract in the presence of vitamin D.
- it promotes the release of calcium and phosphate from the bone to the blood when required.

- it promotes the active reabsorption of calcium ions back to the blood in the kidney, but inhibits the reabsorption of phosphate so that it is excreted.

These actions of calcitonin and parathormone are under negative feedback control from the thyroid and parathyroid glands (not involving the pituitary).
Table 2. summarises the sources and roles of some of the more important minerals in humans.

Suggestions for practical or project work

- **Water culture experiments**. Plants are grown in prepared culture solutions of known composition. One mineral is omitted from each culture solution so that the effect of its absence on the plant growth can be assessed.
- **Ringing experiments**. Cylinders of tissue can be cut away around the circumference of stems of rooted herbaceous or slightly woody plants. The cylinders could include the phloem tissue or the phloem and xylem tissue. The effects of these treatments on the aerial parts of the plant could be observed and explained.
- **Examination and analysis of autoradiographs from radioactive tracer experiments**. The uptake of ions by roots and transport through the plant will have been traced by allowing the plant to absorb radio-active isotopes of the minerals (placed in the soil) and photographing either the whole plant or sections of the plant. Such photographs are called autoradiographs and show the isotope positions by bright areas.

Table 2. Minerals vital to the body

Mineral	Comments	Roles
Calcium *	Found in milk, eggs, green leafy vegetables and shellfish. Absorption from gut depends on the presence of **vitamin D**. The balance of calcium between bone and blood is controlled by the hormones **calcitonin** (from thyroid gland) and **parathormone** (from parathyroid glands).	Component of bones and teeth. Cofactor for blood clotting. Required for normal muscle and nerve activity, cellular motility, exocytosis, endocytosis, chromosome movements in cell division and release of neurotransmitters. Deficiency of calcium could result in **rickets**. Pregnant women require extra calcium to enhance bone growth in the fetus and to prevent calcium transfer from maternal to fetal bone. Lactating mothers require extra calcium which is fed to the baby via the milk and used for bone growth.
Iron *	Good sources are meat, liver, egg yolk, beans, nuts, cereals, shellfish. Higher daily intakes are needed in pregnant women for synthesising fetal haemoglobin. Stored in liver, spleen and red bone marrow as **ferritin**.	66% of body iron is found in **haemoglobin** which is important in blood gas transport. It is also found in **myoglobin** which holds oxygen in muscles and in the **cytochromes** of the electron transport chain. It is required as a cofactor for peroxidase enzymes, such as catalase. Deficiency of iron could result in **anaemia**.
Sodium *	Found in most foods and added as salt to food. Excreted in sweat and urine.	Most abundant cation in extracellular fluid and affects water distribution by osmosis. Essential for nerve impulse conduction. Actively pumped out of cells by sodium pump.
Magnesium	Found in vegetables and most other foods.	Found with calcium in bones and teeth. Required as a cofactor for many enzymes, eg ATPase and hexokinase.
Potassium *	Found in most foods in required amounts. Much is excreted in the urine.	Most abundant cation in intracellular fluids. Essential for nerve impulse conduction and muscle contraction.
Phosphate *	Found in meat, fish, dairy products and nuts. Blood phosphate level is regulated by the hormones **calcitonin** and **parathormone**.	Component of bones and teeth. Provides a major buffer system in blood. Component of DNA and RNA and of energy carrying coenzymes such as ATP. Component of phospholipids found in cell membranes.
Chloride *	Found in most foods as component of salt (NaCl). Found in both extracellular and intracellular fluids. Much excreted in urine.	Involved in acid-base balance of blood and water balance. Required for HCl synthesis in stomach.
Iodine	Found in seafood, iodised salt, cod-liver oil and vegetables grown in iodine rich soil. Deficiency can result in **goitre** (swollen thyroid).	Required by thyroid to synthesize the hormones **thyroxine** and **tri-iodothyronine**. These hormones regulate metabolic rate and growth.
Fluorine	Added to domestic water supplies if natural levels are low.	Component of bones and teeth. Improves resistance to tooth decay and slows development of spinal osteoporosis.
Cobalt	Component of **cyanocobalamin** (Vit B_{12}). Found in liver, kidney, milk, eggs, cheese, meat.	Required for **erythropoiesis** (red cell formation). Deficiency could result in **pernicious anaemia**.
Zinc	Best source in meat.	Component of **carbonic anhydrase** in red blood cells and so important for CO_2 transport in blood.

*specifically named on most syllabusus.

Practice questions.

1. Suggest explanations for each of the following observations:
   (a) Prior to the Clean Air Act (1976) many children in atmospherically polluted areas of Britain suffered from rickets. 4

   (b) When a turgid plant is ringed to include the phloem the leaves above the ring remain turgid. Deeper ringing results in wilting of the leaves above the ring. 3

   (c) People living in areas where soils are iodine deficient may develop swollen necks. 3

   (d) As root hairs absorb positive ions from the soil they discharge equivalent amounts of hydrogen ions. 2
   (12 marks)

2. Suggest six precautions which should be taken when performing a water culture investigation of mineral nutrition in plants. (6 marks)

3. (a) The following statistics (hypothetical) refer to the iron balance of a healthy adult man.
   Daily iron requirement = 8.0 mg.
   Proportion of iron ingested that is absorbed into the blood = 60% (remainder lost in faeces).
   Proportion of iron absorbed that is used by tissues = 75% (remainder lost in urine).

   On a particular day a man obtained all his iron by only eating corned beef. This contains 2.9 mg of iron per 100 g of meat. Calculate the mass of corned beef that the man would need to consume to meet his daily requirement for iron. Show your working. 3

   (b) How does the body gain enough iron if the daily intake is deficient? 2

   (c) Milk only contains 0.1mg of iron per 100 g of milk which is less than a baby needs. Suggest how the development of anaemia may be avoided in babies. 2
   (7 marks)

4. Briefly explain why:
   (a) Calcium is important to animals and plants. 2
   (b) Some enzymes need metallic cofactors. 2
   (4 marks)

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